FCF-TRT-0877

Ionizing Radiation Test Report for FCF Hardware Tested November 2002

Fluids and Combustion Facility

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PREFACE

Under the Microgravity Research, Development, and Operations Contract (MRDOC), the National Aeronautics and Space Administration (NASA) is developing a modular, multi-user experimentation facility for conducting fluid physics and combustion science experiments in the microgravity environment of the International Space Station (ISS). This facility, called the Fluids and Combustion Facility (FCF), consists of two test platforms: the Fluids Integrated Rack (FIR), and the Combustion Integrated Rack (CIR). Also included in MRDOC are the required support efforts for Mission Integration and Operations, consisting of the Telescience Support Center (TSC) and Mission Integration and Planning (MIP).

This document will detail the results of ionizing radiation testing for FCF hardware that was tested in November 2002.

SIGNATURE PAGE

IONIZING RADIATION TEST REPORT FOR FCF HARDWARE TESTED NOVEMBER, 2002
FOR THE
FLUIDS AND COMBUSTION FACILITY

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REVISION PAGE

IONIZING RADIATION TEST REPORT FOR FCF HARDWARE TESTED NOVEMBER, 2002 FOR THE FLUIDS AND COMBUSTION FACILITY

Revision	Date	Description of Change or ECOs Incorporated	Contractor Verification and Date	NASA Verification and Date*
Final	04/09/03	Initial release of test results for FCF hardware tested in November, 2002	Review	N/A

***Enter "N/A" if NASA approval is not required by contract.

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1.0 INTRODUCTION

1.1 Purpose

The purpose of this report is to document the results of the ionizing radiation tests on the following electronic hardware as part of the Fluids and Combustion Facility (FCF). The purpose of the test was to verify the functionality and determine a representative Mean Time Between Failures (MTBF) for various failure modes of the hardware when exposed to a 10 year equivalent dose of ionizing radiation as will be present within the US Lab module of the International Space Station (ISS). Results from this test will be used to provide a go/no-go condition on the engineering design of the FCF or drive changes to our current spares philosophy to support meeting the FCF Operational Availability Requirement of 83%.

The list of hardware that was tested in November 2002 is as follows:

ATCU Fan – EBM Industries Inc. – R1G220-AB35-52

I/OP 24+2 Ethernet Switch – Continuous Computing 0-02627

I/OP SCSI Hard Drive – Seagate Barracuda ST11841677LWV

IPSU SCSI Hard Drive – Seagate Cheetah ST318203LW

1.2 Scope

These test results are to be considered one set of results in a series of test results culminating in a final quality assurance/acceptance test of the flight unit hardware involved in ionizing radiation testing.

2.0 DOCUMENTS

This section lists specifications, models, standards, guidelines, handbooks, and other special publications. These documents have been grouped into two categories: applicable documents and reference documents.

2.1 Order of Precedence for Documents

In the event of a conflict between this document and other documents specified herein, the requirements of this document shall apply. In the event of a conflict between this document and the contract, the contractual requirements shall take precedence over this document. In the event of a conflict between this document and higher level documents, the higher level documents shall take precedence over this document.

All documents used, applicable or referenced, are to be the issues defined in the current version of the MRDOC contract. Nothing in this document supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.2 Applicable Documents

The documents in Table 1 are applicable to the FCF Project to the extent specified herein.

TABLE I. Applicable Documents

SSP30512	Space Station Ionizing Radiation Design Environment
SSP50005	ISS FLIGHT CREW INTEGRATION STD (NASA-STD-3000/T)
FCF-TPP-0761	Radiation Susceptibility Test Plan for the Fluids and Combustion Facility (FCF)
JSC 29987	Radiation Test Report For Elements of the Fluids and Combustion Facility (FCF)

2.3 Reference Documents

The documents in Table 2 are provided only as reference material for background information and are not imposed as requirements.

TABLE II. Reference Documents

PD-ED-1258	Space Radiation Effects on Electronics Components in Low-Earth Orbit
NASA/CR-1998-208593	Space Environment Effects: Low-Altitude Trapped Radiation Model
LLIS Database Entry 0792	Radiation Design Margin Requirement
LLIS Database Entry 0824	Space Radiation Effects on Electronic Components in Low-Earth Orbit

IEEE Trans. On Nucl. Sci. **45**, 2467-2474 (1998)	Internuclear Cascade-Evaporation Model for LET Spectra of 200 MeV Protons

3.0 TEST SUMMARY

The test was conducted at the Indiana University Cyclotron Facility (IUCF) in Bloomington Indiana. The test was setup and instrumented according to FCF-TPP-0761, Fluids and Combustion Facility Radiation Susceptibility Test Plan.

The individual run results are found in Appendix B.

The purpose of this test is to determine the MTBF of various electronic components due to Single Event Effects (SEE). The components will be subjected to a 200 MeV proton beam (Indiana University) to a total fluence of 10^{10} p^+/cm^2. Components will be monitored during exposure to determine when an error occurs as well as what type of error. A fluence of 10^{10} p^+/cm^2 provides a Total Ionizing Dose (TID) of 600 rad(Si) This provides an approximate 2 times safety factor versus the expected Total Ionizing Dose as specified in SSP30512 (corresponding verification was found in SSP50005 involving human exposure to ionizing radiation). Use of 200 MeV protons probes the linear energy transfer (LET) region to 14 MeV cm^2/mg in Silicon. Given the USLab environment, probing out to 14 MeV/μm gives an upper limit of 10 years MTBF. Thus, a null result (no errors) means a component has at least a 10 year MTBF. Note that this holds only for Silicon using a data analysis program developed by Johnson Space Center (PRODUCT). Interpretation of effects on non-Silicon based components (i.e. crystalline optics) requires a different LET for 200 MeV protons, which can be calculated knowing the cross section of the material. The calculated MTBFs as generated from a data analysis program developed by Johnson Space Center called PRODUCT. Results can be found in Appendix C as the Johnson Space Center Report JSC 29987 dated December 2002.

4.0 RESULTS

4.1 Impacts Of Identified Single Event Effect Occurrences on Operational Availability

There is no reported impact on the operational availability of the ATCU and subsequently the Common Environmental Control System (ECS) as a result of testing the ATCU Fan. No errors were encountered.

There is no reported impact on the operational availability of the I/OP as a result of testing the I/OP Ethernet Switch. No errors were encountered.

The errors that were encountered while testing the I/OP SCSI Hard Drive produced an overall MTBF of 58.2 days (56.0 days after review and 1 error correction, see NOTE 1 below). These errors consisted of functional interrupts and data corruption errors. In most instances a recycling of power to the hard drive was needed to correct the error. The I/OP main processor has the ability to detect hard drive disc errors. After a read/write error has been verified (3 consecutively reported errors) the main processor will cycle power to the hard drive in question and re-initialize the hard drive. The I/OP will then attempt to start reading/writing to the hard drive. There is a loss of telemetry that is being stored on the hard drive. All telemetry is still being processed through the ISS Multiplexer-Demultiplexer (MDM) and reported to ground for ground monitoring. There is no reported impact on the operational availability of the I/OP as a result of testing the I/OP SCSI Hard Drive.

The errors that were encountered while testing the IPSU SCSI Hard Drive produced an overall MTBF of 33.6 days (36.4 days after review and 1 error correction, see NOTE 1 below). These errors consisted of functional interrupts and data corruption errors. In most instances a recycling of power to the hard drive was needed to correct the error. Once again the IPSU main processor has the ability to detect hard drive disc errors. After a read/write error has been verified (10 consecutively reported errors) the main processor will switch the read/write function being executed to the operable hard drive**.** These errors should be transparent to the IPSU system, but will be recognized by ground support personnel, who will initialize a command to cycle power to the IPSU, re-initialize the hard drive in question and verify proper operation after the current image acquisition phase has been completed. Actual in-lab testing demonstrated that less than 1% of images would be lost for the worst-case acquisition mode. There is only a minimal reported impact on the operational availability of the IPSU as a result of testing the IPSU SCSI Hard Drive.

The FIR Fluids Science Avionics Package (FSAP) utilizes the same hard drive and main processor that the IPSU uses. The FSAP mainly utilizes the hard drives to store digitally acquired analog measurements and digitized video. The FSAP main processor has the ability to detect hard drive disc errors. After a read/write error has been verified (10 consecutively reported errors), the main processor will switch the read/write function being executed to the operable hard drive. This will result in some reduced capability. At a minimum, this will include a reduction of the storage space, although one drive operation will meet the C-spec disk storage space requirements. While the majority of the data acquisition cases can still be performed, the envelope of data (voltage and image) acquisition worst-case rates may not be met by one drive operation. Recovery plans during experiment operations, including power cycling during an experiment run when the FSAP collecting data and controlling the operation of the PI hardware and FCF diagnostics, are mostly impractical. These errors will be recognized by ground support personnel, who will initialize a command to cycle power to the FSAP, re-initialize the hard drive in question and verify proper operation after the current experiment operational phase has been completed.

NOTE 1: This MTBF data was pulled directly from the JSC report found in Appendix C. A thorough review of the input data points found two slight errors, which were corrected, and the programs reran to obtain the updated MTBF numbers presented above.

5.0 CONCLUSIONS

5.1 Comparison to Success Criteria

As a result of a review of susceptibility of ionizing radiation induced events (did we see any errors), occurrence of ionizing radiation induced events (MTBF), and subsequent mitigation philosophies for the specific hardware tested during this round of testing, the results of this testing produced no failures/errors that would have a significant impact on the continued proper operation of the FCF system. Actual impact on individual science results (corrupted science data, rate of science data acquisition) will need to be addressed on an individual basis.

6.0 RECOMMENDATIONS

6.1 Testing Recommendations

From this initial round of ionizing radiation testing the following recommendations are being noted for subsequent planned testing.

*Record as much information as possible to describe the error in question (i.e. current increase versus nominal, source of error if it can be determined, detailed information on the type of corrupted data).

*Record as much information as possible about the recovery methodology utilized to recover from the error (i.e. keystrokes utilized to recover, recycling of power, current draw after recovery).

*Provide as much cross training (multi-tasking) as possible for test team members to assist in a steady flow of testing.

*Provide access to a printer to capture actual ionizing radiation based RAM or memory error data for subsequent review during test root cause analysis.

*Develop the capability to perform some type of current limiting at the power supply to minimize the chances of encountering a truly destructive event. This will require a full understanding of true base line nominal current draws under maximum nominal conditions.

6.2 Lessons Learned

From this initial round of ionizing radiation testing the following lessons learned are being documented for subsequent planned testing.

*Verify adequate function of test set-up utilizing actual test support hardware, as it will be configured at the IUCF in the lab prior to departure to the IUCF.

*An attempt to pre-classify known error types (i.e. Single Event Latchups that are corrected by an auto-reset of board function, Single Event Latchups that are corrected by a recycle of power to obtain board function, a RAM or memory error) and then consistently utilize these pre-defined error classifications throughout subsequent testing.

*There may not be a need to attempt to isolate each individual chip or small groups of chips for each ionizing radiation exposure. Based upon functionality, we may be able to identify zones on printed circuit boards versus trying to isolate to smaller individual chips or small groups of chips. Larger target areas can potentially speed up the testing and allow for a greater amount of hardware to be tested.

APPENDIX A ACRONYMS

ATCU	Air Thermal Control Unit
CIR	Combustion Integrated Rack
ECS	Environmental Control System
FCF	Fluids and Combustion Facility
FI	Functional Interrupt
FIR	Fluids Integrated Rack
FSAP	Fluids Science Avionics Package
GRC	Glenn Research Center
I/OP	Input/Output Processor
IPSU	Image Processing Storage Unit
ISS	International Space Station
IUCF	Indiana University Cyclotron Facility
JSC	Johnson Space Center
LET	Linear Energy Transfer
MDM	Multiplexer-Demultiplexer
MIP	Mission Integration and Planning
MRDOC	Microgravity Research, Development, and Operations Contract
MTBF	Mean Time Between Failures
NASA	National Aeronautics and Space Agency
SAA	South Atlantic Anomaly
SCSI	Small Computer System Interface
SEB	Single Event Burnout
SEE	Single Event Effects

SEL	Single Event Latchup
SEU	Single Event Upset
TID	Total Ionizing Dose
TSC	Telesciences Support Center

APPENDIX B RESULTS OF PROTON BEAM TESTING OF FCF COMPONENTS

Results of Proton Beam Testing of FCF Components

Run No.	Assembly	Position No.	Component ID	Component No.	Component Description	Vignette	Fluence	Percentage of Full Dose	Results
1	ATCU Fan	1			Power Mosfets	None	5.01E+09	50%	Fan ran continuosly @ 1500 RPM. No effects.
2	ATCU Fan	1			Power Mosfets	None	1.00E+10	100%	Fan ran continuosly @ 2700 RPM. No effects.
3	FIOP 2+24 Ethernet Switch	1		2-Altima 0031TA AC104-QF CC509501B3		1 X 2.5	1.00E+10	100%	No effects on ping.
4	FIOP 2+24 Ethernet Switch	2		2-Altima 0031TA AC104-QF CC509501B3		1 X 2.5	1.00E+10	100%	No effects on ping.
5	FIOP 2+24 Ethernet Switch	5		1-GigaPHY AM 79761YC-14 0023CMAP and 1-?? 0-02788SWO-02	Flash	1 X 2.5	1.00E+10	100%	No effects on ping.
6	FIOP 2+24 Ethernet Switch	4		2-GS88032T-100 C162806011		1 X 2.5	1.00E+10	100%	No effects on ping.
7	FIOP 2+24 Ethernet Switch	6		2-MT 48LC4M16A2		1.25 X 1.25	1.00E+10	100%	No effects on ping.
8	FIOP 2+24 Ethernet Switch	3		Vertex Networks DS213-B DA7055040	Network Controller	1.25 X 1.25	1.00E+10	100%	No effects on ping.

9	FIOP 2+24 Ethernet Switch	7		Motorola XPC850DEZT66T QQEP0031S	Processor	1.25 X 1.25	1.00E+10	100%	No effects on ping.
10	FIOP 2+24 Ethernet Switch	8				1.25 X 1.25	1.00E+10	100%	No effects on ping.
11	FIOP 2+24 Ethernet Switch	9			Oscillator	1.25 X 1.25	1.00E+10	100%	No effects on ping.
12	FIOP 2+24 Ethernet Switch	10				1.25 X 1.25	1.00E+10	100%	No effects on ping.
13	FIOP 2+24 Ethernet Switch	11		2-Altima 0031TA AC104-QF CC509501B3		2 X 2.25	1.00E+10	100%	No effects on ping.
14	FIOP 2+24 Ethernet Switch	12		2-GS88032T-100 C162806011 and other chips		2 X 2.25	1.00E+10	100%	No effects on ping.
15	FIOP 2+24 Ethernet Switch	13		Vertex Networks DS213-B DA7055040 and other chips	Network Controller	2 X 2.25	1.00E+10	100%	No effects on ping.
16	FIOP 2+24 Ethernet Switch	14		1-GigaPHY AM 79761YC-14 0023CMAP		2 X 2.25	1.00E+10	100%	No effects on ping.
17	FIOP 2+24 Ethernet Switch	15				2 X 2.25	1.00E+10	100%	No effects on ping.
18	FIOP Seagate Barracuda - ST1181677LWV	1		Seagate (CARMEL) - 100280-502	SCSI Controller	1 x 1.5	8.86E+08	9%	Write with Beam On / Read with Beam Off Functional Interrupt (F1) Recycle Power to Hard Drive
19	FIOP Seagate Barracuda - ST1181677LWV	1		Seagate (CARMEL) - 100280-502	SCSI Controller	1 x 1.5	5.01E+09	50%	Write with Beam On / Read with Beam Off No Additional Read Errors

20	FIOP Seagate Barracuda - ST1181677LWV	1		Seagate (CARMEL) - 100280-502	SCSI Controller	1 x 1.5	1.00E+10	100%	Write with Beam Off / Read with Beam On No Additional Read Errors
21	FIOP Seagate Barracuda - ST1181677LWV	2		Winbond - W986416CH-8H	RAM	1 x 1.5	5.00E+09	50%	Write with Beam Off / Read with Beam On No Additional Read Errors
22	FIOP Seagate Barracuda - ST1181677LWV	3		Winbond - W986416CH-8H	RAM	1 x 1.5	5.01E+09	50%	Write with Beam Off / Read with Beam On No Additional Read Errors
23	FIOP Seagate Barracuda - ST1181677LWV	4		Marvell - 88c5200	Read/Write	1 x 1.5	5.01E+09	50%	Write with Beam Off / Read with Beam On No Additional Read Errors
24	FIOP Seagate Barracuda - ST1181677LWV	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	8.99E+08	9%	Write with Beam Off / Read with Beam On Functional Interrupt (F1) Recycle Power to Hard Drive
25	FIOP Seagate Barracuda - ST1181677LWV	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	1.29E+09	13%	Write with Beam Off / Read with Beam On Functional Interrupt (F1) Recycle Power to Hard Drive
26	FIOP Seagate Barracuda - ST1181677LWV	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	2.36E+09	24%	Write with Beam Off / Read with Beam On Functional Interrupt (F1) Recycle Power to Hard Drive
27	FIOP Seagate Barracuda - ST1181677LWV	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	2.75E+09	28%	Write with Beam Off / Read with Beam On Functional Interrupt (F1) Recycle Power to Hard Drive
28	FIOP Seagate Barracuda - ST1181677LWV	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	3.11E+09	31%	Write with Beam Off / Read with Beam On Functional Interrupt (F2) Data Corrupted Finished Run Until 5E+09
29	FIOP Seagate Barracuda - ST1181677LWV	6		Infineon - C163-24D and FL INTLOGIC	ED Ram	1 x 1.5	5.01E+09	50%	Write with Beam Off / Read with Beam On No Additional Read Errors

30	FIOP Seagate Barracuda - ST1181677LWV	7		?? - 29F00BTC	Flash Memory	1 x 1.5	5.00E+09	50%	Write with Beam Off / Read with Beam On No Additional Read Errors
31	FIOP Seagate Barracuda - ST1181677LWV	2		Winbond - W986416CH-8H	RAM	1 x 1.5	1.00E+10	100%	Write with Beam On / Read with Beam Off No Additional Read Errors
32	FIOP Seagate Barracuda - ST1181677LWV	3		Winbond - W986416CH-8H	RAM	1 x 1.5	1.00E+10	100%	Write with Beam On / Read with Beam Off No Additional Read Errors
33	FIOP Seagate Barracuda - ST1181677LWV	4		Marvell - 88c5200	Read/Write	1 x 1.5	1.00E+10	100%	Write with Beam On / Read with Beam Off No Additional Read Errors
34	FIOP Seagate Barracuda - ST1181677LWV	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	6.21E+09	62%	Write with Beam On / Read with Beam Off Functional Interrupt (F1) Recovered Automatically With Beam Removal
35	FIOP Seagate Barracuda - ST1181677LWV	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	6.46E+09	65%	Write with Beam On / Read with Beam Off Functional Interrupt (F1) Recovered Automatically With Beam Removal (Note: Power Recycled To Remove Residues)
36	FIOP Seagate Barracuda - ST1181677LWV	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	6.55E+09	66%	Write with Beam On / Read with Beam Off Functional Interrupt (F2) No Auto Recovery Recycle Power To Hard Drive
37	FIOP Seagate Barracuda - ST1181677LWV	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	7.24E+09	72%	Write with Beam On / Read with Beam Off Functional Interrupt (F1) Finished Run Until 5E+09
38	FIOP Seagate Barracuda - ST1181677LWV	6		Infineon - C163-24D and FL INTLOGIC	ED Ram	1 x 1.5	1.00E+10	100%	Write with Beam On / Read with Beam Off No Additional Read Errors

39	FIOP Seagate Barracuda - ST1181677LWV	7		?? - 29F00BTC	Flash Memory	1 x 1.5	1.00E+10	100%	Write with Beam On / Read with Beam Off No Additional Read Errors
40	FIOP Seagate Barracuda - ST1181677LWV	8		Lower Right Quadrant		2 X 2.25	5.01E+09	50%	Write with Beam On / Read with Beam Off No Additional Read Errors
41	FIOP Seagate Barracuda - ST1181677LWV	8		Lower Right Quadrant		2 X 2.25	1.00E+10	100%	Write with Beam Off / Read with Beam On No Additional Read Errors
42	FIOP Seagate Barracuda - ST1181677LWV	9		Upper Left Quadrant		2 X 2.25	4.55E+09	46%	Write with Beam Off / Read with Beam On Read Errors Attributable To Master Computer
43	FIOP Seagate Barracuda - ST1181677LWV	9		Upper Left Quadrant		2 X 2.25	5.04E+09	50%	Write with Beam Off / Read with Beam On No Additional Read Errors
44	FIOP Seagate Barracuda - ST1181677LWV	9		Upper Left Quadrant		2 X 2.25	1.00E+10	100%	Write with Beam On / Read with Beam Off No Additional Read Errors
45	CIPSU Seagate Cheetah - ST318203LW	1		Seagate - 100280-502	SCSI Controller	1 x 1.5	5.00E+09	50%	Write with Beam On / Read with Beam Off No Additional Read Errors
46	CIPSU Seagate Cheetah - ST318203LW	1		Seagate - 100280-502	SCSI Controller	1 x 1.5	1.00E+10	100%	Write with Beam On(OK)/Read with Beam On No Additional Read Errors
47	CIPSU Seagate Cheetah - ST318203LW	2		Winbond - W981616AH-8	RAM	1 x 1.5	5.01E+09	50%	Write with Beam On(OK)/Read with Beam On No Additional Read Errors
48	CIPSU Seagate Cheetah - ST318203LW	3		Winbond - W981616AH-8	RAM	1 x 1.5	4.52E+09	45%	Write with Beam On(OK)/Read with Beam On Functional Interrupt (F1) Recycle Power To Hard Drive Reboot OK No Data Corrupted (Loop 7/Segment 5 of 16/Partition G)

49	CIPSU Seagate Cheetah - ST318203LW	3		Winbond - W981616AH-8	RAM	1 x 1.5	5.54E+09	55%	Write with Beam On(OK)/Read with Beam On No Additional Read Errors
50	CIPSU Seagate Cheetah - ST318203LW	4		Marvell - 88c4200	Read/Write	1 x 1.5	5.04E+09	50%	Write with Beam On(OK)/Read with Beam On No Read Errors
51	CIPSU Seagate Cheetah - ST318203LW	6		Infineon - C163-24D and ????????	ED Ram	1 x 1.5	5.01E+09	50%	Write with Beam On(OK)/Read with Beam On No Read Errors
52	CIPSU Seagate Cheetah - ST318203LW	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	1.70E+08	2%	Write with Beam On(OK)/Read with Beam On Functional Interrupt (F1) Recycle Power To Hard Drive Soft Reboot To CPU Reboot OK No Data Corrupted (Loop 1/Block 10/Drive E) (Delta Current = 20mA)
53	CIPSU Seagate Cheetah - ST318203LW	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	2.30E+08	2%	Write with Beam On(OK)/Read with Beam On Functional Interrupt (F1) Recycle Power To Hard Drive Soft Reboot To CPU Reboot OK No Data Corrupted (Loop 1/Block 11/Drive G) (Delta Current = 20mA)
54	CIPSU Seagate Cheetah - ST318203LW	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	4.46E+08	4%	Write with Beam On(OK)/Read with Beam On Functional Interrupt (F1) Recycle Power To Hard Drive Soft Reboot To CPU Reboot OK No Data Corrupted (Loop 3/Block 8/Drive G) (Delta Current = 20mA)
55	CIPSU Seagate Cheetah - ST318203LW	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	6.34E+08	6%	Write with Beam On(OK)/Read with Beam On Functional Interrupt (F1) Recycle Power To Hard Drive Soft Reboot To CPU Reboot OK No Data

									Corrupted (Loop 2/Block 8/Drive G) (Delta Current = 20mA)
56	CIPSU Seagate Cheetah - ST318203LW	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	5.02E+09	50%	Finished Run To 5.00E+09
57	CIPSU Seagate Cheetah - ST318203LW	7		Atmel - AT49F4096A	4Mbit Flash Memory	1 x 1.5	5.00E+09	50%	Write with Beam On(OK)/Read with Beam On Recycle Power To Hard Drive Soft Reboot To CPU Reboot OK No Data Corrupted
58	CIPSU Seagate Cheetah - ST318203LW	7		Atmel - AT49F4096A	4Mbit Flash Memory	1 x 1.5	1.00E+10	100%	Write with Beam On/Read with Beam Off Recycle Power To Hard Drive Reboot OK No Data Corrupted
59	CIPSU Seagate Cheetah - ST318203LW	2		Winbond - W981616AH-8	RAM	1 x 1.5	1.00E+10	100%	Write with Beam On/Read with Beam Off No Data Errors
60	CIPSU Seagate Cheetah - ST318203LW	3		Winbond - W981616AH-8	RAM	1 x 1.5	1.05E+10	105%	Write with Beam On/Read with Beam Off No Data Errors
61	CIPSU Seagate Cheetah - ST318203LW	4		Marvell - 88c4200	Read/Write	1 x 1.5	1.00E+10	100%	Write with Beam On/Read with Beam Off No Data Errors
62	CIPSU Seagate Cheetah - ST318203LW	6		Infineon - C163-24D and ????????	EDRam	1 x 1.5	8.24E+09	82%	Write with Beam On/Read with Beam Off Functional Interrupt (F1-System Latch) Harddrive Auto Recovered When Beam Was Removed No Data Corrupted

63	CIPSU Seagate Cheetah - ST318203LW	6		Infineon - C163-24D and ????????	EDRam	1 x 1.5	1.01E+10	101%	Write with Beam On/Read with Beam Off Functional Interrupt (F1-Write Function Sluggish) (Delta Current = 50mA When Sluggish) Beam Removed And Was Still Sluggish/Power Recycled Drive/Still Slow/Soft Reboot CPU No Data Errors
64	CIPSU Seagate Cheetah - ST318203LW	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	6.35E+09	64%	Write with Beam On/Read with Beam Off Functional Interrupt (F1-Write Function Sluggish) Power Recycled Drive/Still Slow/Power Recycled CPU
65	CIPSU Seagate Cheetah - ST318203LW	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	6.53E+09	65%	Write with Beam On/Read with Beam Off Functional Interrupt (F1-Write Function Sluggish) and Functional Interrupt (F2-System Locked Up) Power Recycled Drive/Power Recycled CPU No Data Errors
66	CIPSU Seagate Cheetah - ST318203LW	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	6.63E+09	66%	Write with Beam On/Read with Beam Off Functional Interrupt (F2-System Locked Up) and Functional Interrupt (F3-Data Errors) Power Recycled Drive/Power Recycled CPU
67	CIPSU Seagate Cheetah - ST318203LW	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	7.09E+09	71%	Write with Beam On/Read with Beam Off Functional Interrupt (F2-System Locked Up) and Functional Interrupt (F3-Data Errors) Power Recycled Drive/Power Recycled CPU

68	CIPSU Seagate Cheetah - ST318203LW	5		TI - D731586APGJ	Servo ASIC DSP	1 x 1.5	7.32E+09	73%	Write with Beam On/Read with Beam Off Functional Interrupt (F2-System Locked Up) Power Recycled Drive/Power Recycled CPU Finished Run Until 1.04E+10
69	CIPSU Seagate Cheetah - ST318203LW	8		Lower Right Quadrant		2 X 2.25	5.02E+09	50%	Write with Beam On(OK)/Read with Beam On No Data Errors
70	CIPSU Seagate Cheetah - ST318203LW	8		Lower Right Quadrant		2 X 2.25	1.00E+10	100%	Write with Beam On(OK)/Read with Beam On No Data Errors
71	CIPSU Seagate Cheetah - ST318203LW	9		Upper Left Quadrant		2 X 2.25	5.01E+09	50%	Write with Beam On(OK)/Read with Beam On No Data Errors
72	CIPSU Seagate Cheetah - ST318203LW	9		Upper Left Quadrant		2 X 2.25	1.00E+10	100%	Write with Beam On(OK)/Read with Beam On No Data Errors

APPENDIX C RADIATION TEST REPORT FOR ELEMENTS OF THE FLUIDS AND COMBUSTION FACILITY (FCF)

JSC 29987

RADIATION TEST REPORT FOR ELEMENTS OF THE FLUIDS AND COMBUSTION FACILITY (FCF)

ENGINEERING DIRECTORATE

AVIONICS SYSTEMS DIVISION

December, 2002

National Aeronautics and Space Administration
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1.0 INTRODUCTION

Candidate elements of the Fluid Combustion Facility (FCS) for the International Space Station (ISS) were tested at the Indiana University Cyclotron Facility (IUCF) to assess susceptibility of the unit to high-energy ionizing radiation.

The test was conducted on December *(actually November)* 18 - 19, 2002 and the summary results are presented in this report.

The members of the test team were:

Tom Young – Reliability/Quality Assurance Engineer, Hernandez Engineering Inc., Test Conductor

Kyson Nguyen, Test Engineer, Lockheed-Martin

John Thomas, NASA FCF Avionics Lead, Glenn Research Center

Henry Yee, Quality Assurance Representative, SAIC-Glenn Research Center

John Zoldak, LMM Software/Electrical Lead, Northrop Grumman Info. Tech.

Ron Gliebe, LMM Electrical Designer, Northrop Grumman Info. Tech.

Louis Chestney, LMM Software Lead, Northrop Grumman Info. Tech.

Yue Liu, Quality Assurance/Engineering Intern, Hernandez Engineering Inc.

Dr. Ken Murray, IUCF, Senior Radiation Effects and Dosimetry Consultant

2.0 TEST OBJECTIVES

The objectives of the radiation testing were to obtain data to make preliminary estimates of ionizing radiation induced functional interrupt rates and other error rates that can be expected on orbit.

3.0 BACKGROUND

A definition of the test philosophy and the radiation environment model used is presented in this section.

3.1 Radiation Test Philosophy Hardware elements must be able to operate in the environment for the duration of their missions. The two major elements of the ionizing radiation environment are the deposition of energy from Total Ionizing Dose (TID) and the Single Event Effects (SEE) produced by high energy particles like protons and atomically heavier ions. The TID experienced by any hardware element is a function of its location on the vehicle. Shielding values are available for various locations within the spacecraft. The SEE's experienced on orbit are not substantially mitigated by shielding because of the high energy of the particles producing the effects.

Radiation testing for SEE's with high energy protons is designed to establish the susceptibility of a given test article to trapped protons in the South Atlantic Anomaly (SAA) and heavy ions due to Galactic and Solar Cosmic Rays. A SEE can be detected as:

- **Single Event Upset (SEU)** – an event like a bit flip resulting in a data error only.
- **Functional Interrupt (FI)** – an event requiring a software reboot or a power cycle.
- **Single Event Latchup (SEL)** – an event where the device has an abnormal conduction path established by the ionizing radiation and as indicated by a primary power supply current change. Power must be recycled to regain control and/or to save the device from destruction.
- **Single Event Burnout (SEB)** – an event where the device has an abnormal conduction path established by the ionizing radiation and is destroyed almost immediately.

The occurrence of a SEE is a single sample observed from a random process. The more samples (in this case SEE's detected) observed, the better the estimate of the Mean Time Between Failures (MTBF) for that specific type of SEE. The goals of this testing are to establish estimates of the MTBF's for each type of SEE detected for a given test article or electronic component.

The probability of an SEE occurring within a test article is related to the number of particles per square centimeter (called fluence) allowed to impinge on the device. The general criterion used in testing with protons is to expose each beam position or test article to a fluence of 10 billion (1E10) protons/cm2.

Even though the SEE susceptibilities measured during testing were only from proton testing, the MTBF's cited in this report are the composite MTBF's due to the nominal proton (primarily SAA trapped protons) and the nominal heavy ion (Galactic Cosmic Rays) environments. The procedures for deriving the MTBF's were determined using the software tool PRODUCT [10]. The proton SEE MTBF's from proton test results were determined using the Bendel A method and are described in [6]. The heavy ion SEE MTBF from proton test results was calculated as described in [5] and [7], using the formula:

MTBF = 6 years/Number of SEE's in 1E10 protons/cm2

<u>3.2 Radiation Environment Definition</u> For typical orbits for the space shuttle or the space station considered here (51.6 - 57 degree inclination, 270 nmi altitude), the nominal

ionizing radiation environment consists of Galactic Cosmic Rays and trapped protons and electrons. The Galactic Cosmic Ray flux was modeled with a solar modulation algorithm [1], [2] whose accuracy has been demonstrated over four solar cycles. The trapped proton and electron radiation spectrum was generated using the AP8 model with solar minimum conditions (1964 epoch, 1965 International Geomagnetic Reference Field (IGRF)) [3]. Orbit average environments were determined for solar minimum conditions with 0.1" thick spherical aluminum shielding for quiet conditions and no earth shadow. Transport and geomagnetic shielding models can be found in [4]. The trapped electron spectrum was only used for TID calculations. These environments are consistent with those defined in [8] and [9].

4.0 GENERAL DISCUSSION

All testing was done with a proton beam energy of 197 Million-electron Volts (MeV). The normal beam diameter of approximately 6 cm was passed through various copper vignettes to adjust the size of the final beam allowed to radiate the test article. The beam positions and required vignettes were pre-planned and documented in the expected order of execution.

4.1 Test Hardware

The following elements of the FCF were tested between November 18 and 19, 2002:

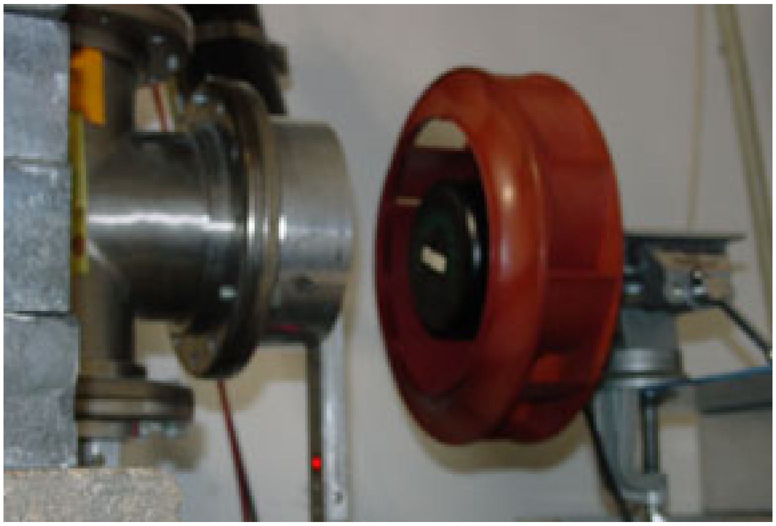
1. ATCU Fan
2. IOP Ethernet Switch
3. IOP Seagate Barracuda HDD
4. IPSU Seagate Cheetah HDD

5.0 SUMMARY OF TESTING

The following section discusses the results of testing of each FCF element. Included in the discussion are the MTBF's noted for the elements that reacted to the beam. MTBF's are calculated at the points where errors happened last. The MTBF's reported are the errors expected from both proton and heavy ions.

5.1 ATCU Fan

Figure 1 shows the ATCU fan in the test configuration. One position was tested for this unit, and there was no error.



ATCU Fan

5.2 IOP Ethernet Switch

Figure 2 shows the IOP Ethernet Switch in the test configuration. Fifteen positions were tested for this unit, and there was no error.

IOP Ethernet Switch

5.3 IOP Seagate Barracuda HDD

Figure 3 shows the IOP Seagate Barracuda HDD in the test configuration. Nine positions were tested for this unit.

Seagate Barracuda HDD

Each position was tested for two different modes of operation: writing and reading. Each mode would have accumulated approximately 5.0 E9 protons / cm**2, unless noted otherwise.

Position 1 (SCSI Controller chip and others) experienced 1 functional interrupt during the write mode. The MTBF for this failure 157 days.

Position 2 had no error.

Position 3 had no error.

Position 4 had no error

Position 5 (Servo ASIC DSP chip and others) experienced 5 errors in the Read mode and 4 errors in the Write mode.

In the Read mode, there were two kinds of error:

a. Four functional interrupts that required power recycle to recover. The MTBF for this kind of errors is 122 days.
b. One error in which data were corrupted. The MTBF for this type of error is 894 days.

In the Write mode, there were also two kinds of errors:

a. Three functional interrupts with the system recovered automatically in 2.25 E9 protons / cm**2. The MTBF for this is 133 days.
b. One functional interrupts with no auto recovery in 2.25 E9 protons / cm**2. The MTBF for this is 278 days.

Position 6 had no error.

Position 7 had no error.

Position 8 had no error

Position 9 (chips of unknown P/Ns, functionality and manufacturer(s)) had 1 error in the Read mode, and the MTBF for this is 813 days.

The combined MTBF would be 58.2 days.

5.4 IPSU Seagate Cheetah HDD (No picture is available)

Nine positions were tested for this unit. Each position was tested for two different modes of operation: writing and reading. Each mode would have accumulated approximately 5.0 E9 protons / cm**2, unless noted otherwise.

Position 1 has no error.

Position 2 has no error.

Position 3 has 1 error in the Read mode. The MTBF would be 808 day.

Position 4 has no error.

Position 5 has 4 errors in the Read mode and 5 errors in the Write mode.

In the Read mode, there were 4 errors of the same type; functional interrupts, that required power recycle to recover in 6.34 E8 proton / cm**2. The MTBF for this would be 28 days.

In the Write mode, there were 3 types of errors:

a. Two functional interrupts in which the system wrote very slow right from the beginning. Power recycle was done to restart the system. The MTBF is 34 days.
b. Two functional interrupts with erroneous data. Power recycle was needed to restart. The MTBF is 183 days.
c. One functional interrupt in which the system rebooted by itself. The MTBF is 408 days (2.29 E9 proton / cm**2).

Position 6 has 2 kinds of errors in the Write mode.

a. Functional interrupt that recovered automatically when beam was off. The MTBF is 577 days.
b. Write function was slowed with beam on. MTBF is 324 days.

Position 7 has no error.

Position 8 has no error.

Position 9 has no error.

The combined MTBF is 33.6 days.

6.0 CONCLUSIONS

Each position of all units tested received a minimum fluence of 1E10 protons/cm2, which is equivalent to a TID of 600 Rads(Si). The data indicated that neither SEL nor SEB was experienced. Also, no degradation in performance due to the TID was noted.

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